AN ADJUSTABLE BLOOD PRESSURE CUFF TO CORRECT ERRORS DUE TO VARIATIONS IN ARM CIRCUMFERENCE*

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A well-recognized source of error in the indirect measurement of blood pressure results from using the standard sphygmomanometer cuff for arms of widely different diameters (Pickering, 1955). When the arm is thicker than usual, blood pressure readings are higher than those obtained by direct intra-arterial measurement; when the arm is thinner, the readings are lower. Hence, for correct indirect measurement, the width of the blood pressure cuff should be in proportion to the circumference of the arm (Bordley *et al.*, 1951). Since it is impractical to use a large series of cuffs of different widths, a special cuff was constructed that could be adjusted to the appropriate width for each subject. With this adjustable cuff, the error in blood pressure reading due to variation in the circumference of the arm was largely eliminated.

METHODS

Description of Cuff and Technique of Measurement. An unusually wide rubber blood pressure air bag was constructed, 18 cm. in width, but of standard length (23 cm.) (Fig. 1). A cloth sleeve

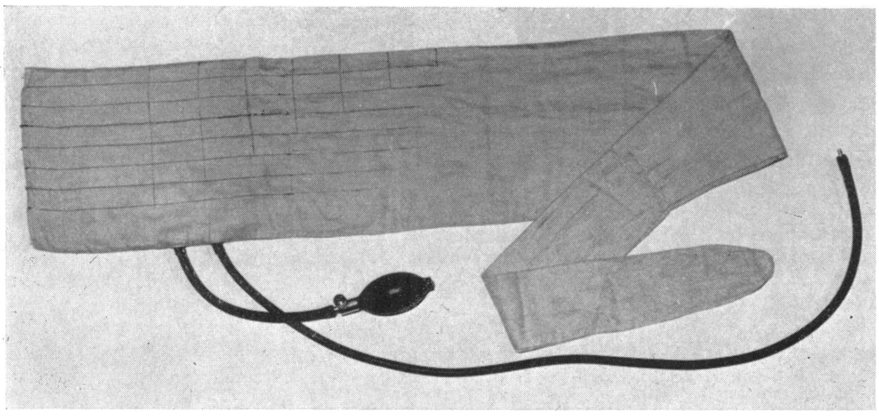

FIG. 1.—Adjustable cuff, 18 cm. in width, inscribed with vertical lines for measurement of arm circumference, each line leading down to a horizontal line marking off a cuff width corresponding to 40 per cent of the measured circumference.

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140 cm. long and appropriately tapered was fitted to the bag. Horizontal lines stitched 2 cm. apart on both surfaces of the cuff were used as guides in folding the cuff. In addition, there were vertical lines 2·5 cm. apart that facilitated measurement of the arm circumference (Fig. 2). Each vertical line led from the upper edge of the cuff down to a corresponding horizontal line that marked off a cuff width corresponding to 40 per cent of the measured circumference. The part of the cuff in excess of the width to be applied to the arm, and lying above the appropriate horizontal line, was folded outward and downward along that line (Fig. 3).

FIG. 2.—Cuff being used to measure circumference of arm.

FIG. 3.—Folded cuff being applied to the arm.

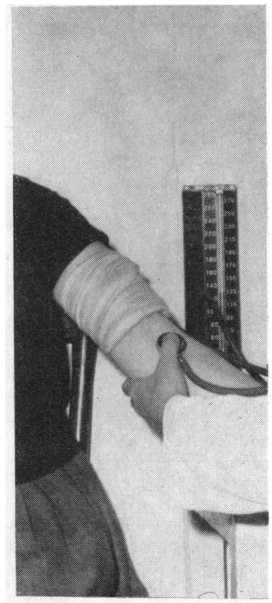

FIG. 4.—Folded cuff fully inflated for determination of blood pressure.

The folded cuff, thus adjusted to a width 40 per cent of the arm circumference, was wrapped around the arm with its lower border 2 cm. above the antecubital fold (arm in 90° flexion). The cloth tail was then wrapped around the cuff in the usual manner, tucking in any excess width of tail, and the cuff was then inflated (Fig. 4).

Pressures were determined repeatedly at half-minute intervals with the cuff folded to the 12 cm. (standard) width until reproducible results were obtained. Subjects with labile pressures which did not stabilize during 3–4 readings were rejected.

Additional determinations were then made with the cuff set at widths of 6 cm., 18 cm., and a width corresponding to 40 per cent of the subject's arm to the nearest cm. ("adjusted cuff"). The order in which these non-standard widths were used was randomized in the series of patients, and with each width 3 successive determinations were made. The average of these 3 determinations was used in the analysis of the results. The 12 cm. width was used again in most patients at the end of the series of determinations, to rule out a progressive change in blood pressure during the course of the measurements.

All measurements were made by the same individual (H.D.), using complete disappearance of Korotkoff sounds as the indicator of diastolic pressure. Subjects in whom the sounds disappeared at pressures below 40 mm. Hg were excluded from the study.

Subjects. Forty-eight adult patients and normal subjects with no cardiovascular abnormalities and blood pressures below 145/95 mm. Hg (standard cuff) were studied. They ranged in age from

16 to 59 years, with an average of 29 (S.D. 11). As many subjects as possible with extremely thick or thin arms were included. The range in arm circumference was from 20 to 44 cm. with an average of 26·4 (S.D. 4·9). Most of the subjects were women 4–7 days post-partum, so that 37 or 77 per cent of the group were females.

RESULTS

The average systolic and diastolic pressure of the group when determined with the narrow (6 cm.) cuff was 127/84, with the standard (12 cm.) cuff 119/74, with the wide (18 cm.) cuff 111/67, and with the "adjusted" cuff 120/76 (Table I). The differences between the readings obtained with the narrow and the standard cuff, and between the standard and the wide cuff, for both systolic and diastolic pressures, were statistically significant (more than 3 × S.E.). The average pressure obtained with the "adjusted" cuff (width 40% of the circumference of the arm) was not significantly different from the reading with the standard cuff. However, with the "adjusted" cuff the readings for the narrowest arms were higher and for the thickest arms lower than with the standard cuff. With arms of medium diameter, the pressures obtained with both cuffs were similar.

TABLE I

STATISTICAL ANALYSIS OF BLOOD PRESSURE MEASUREMENTS WITH CUFF SET AT DIFFERENT WIDTHS

		Width of blood pressure cuff			
		6 cm. (narrow)	12 cm. (standard)	18 cm. (wide)	40% of circ. of arm ("adjusted")
Average blood pressure	S.	126·5	118·7	111·0	120·4
	D.	83·7	73·5	67·4	75·7
Standard deviation of average	S.	15·6	12·0	13·0	10·8
	D.	12·3	11·7	13·9	12·0
Standard error of average	S.	2·4	1·7	1·9	1·5
	D.	1·8	1·7	2·0	1·7
Correlation coefficient, r (B.P. vs. circ.)	S.	0·49	0·56	0·30	0·20
	D.	0·47	0·41	0·24	0·14
Probability of correlation coefficient, r	S.	$p<0·01$	$p<0·01$	$p<0·02$	$p>0·10$
	D.	$p<0·01$	$p<0·02$	$p>0·10$	$p>0·10$
Total variation in B.P. due to variation in circ. ($100 \times r^2$)	S.	25%	30%	9%	4%
	D.	20%	16%	6%	2%
Regression formulæ* y=B.P. in mm. Hg x=circ. in cm.	S.	$y=\underline{1·56}x+85·3$	$y=\underline{1·35}x+81·7$	$y=\underline{0·78}x+90·6$	$y=\underline{0·44}x+107·8$
	D.	$y=\underline{1·18}x+52·5$	$y=\underline{0·98}x+47·6$	$y=\underline{0·70}x+49·0$	$y=\underline{0·36}x+66·2$

* Underlined factor expresses steepness of regression line, another measure of the effect of arm circumference on blood pressure.

S.=systolic B.P.=blood pressure circ.=circumference
D.=diastolic p=probability

Systolic pressures obtained with the standard, narrow and wide cuffs all showed highly significant positive correlation with the arm circumference (Fig. 5 and Table I). Diastolic pressures obtained with the narrow and standard cuffs also showed high degrees of correlation with arm circumference, although with the wide cuff the positive correlation was not statistically significant. Thus it was demonstrated that the wider the cuff, the lower the pressure for a given arm, and the thicker the arm, the higher the pressure reading with a cuff of fixed width. A summary of the statistical analysis of the data is given in Table I.

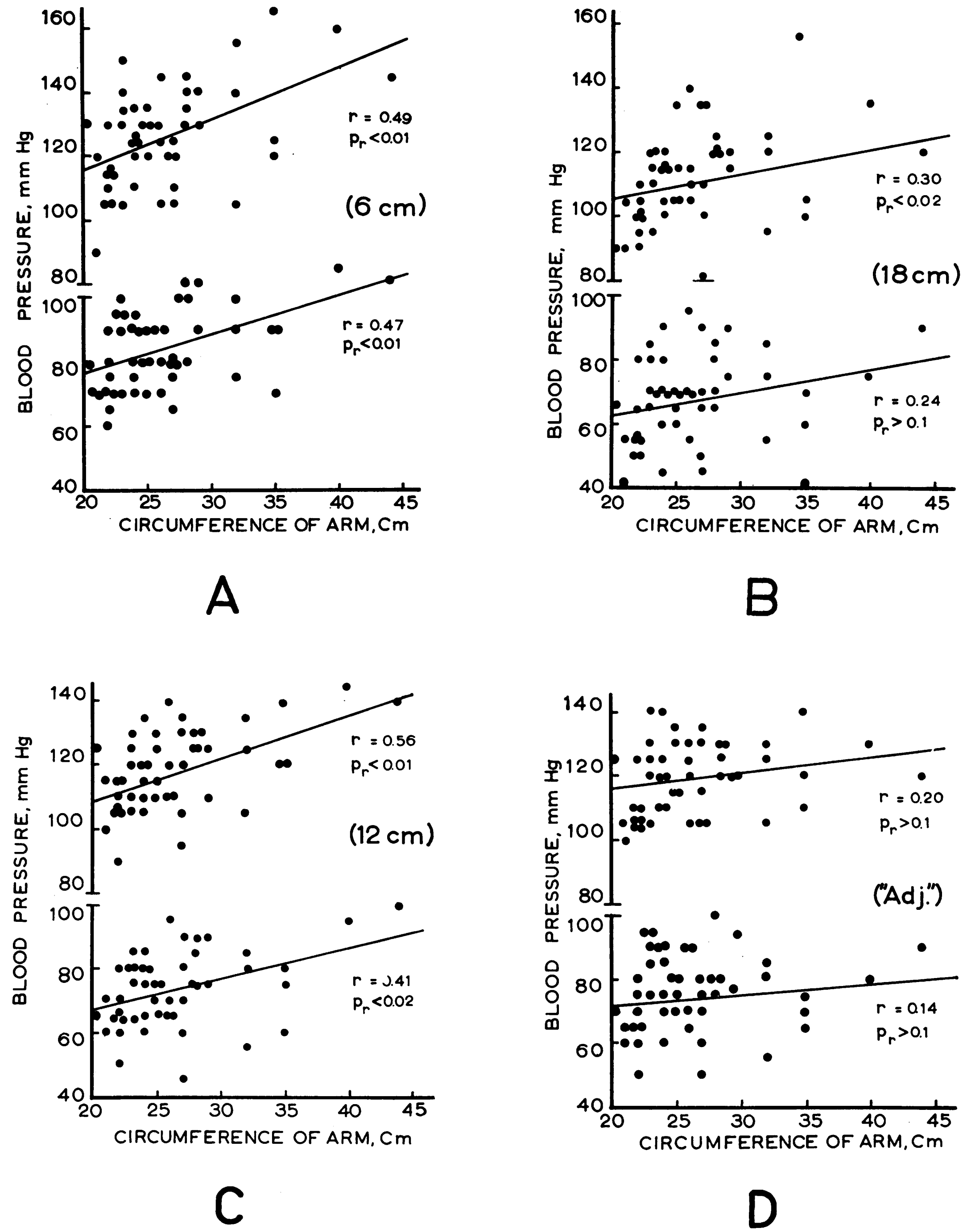

FIG. 5.—Blood pressure determination in 48 normotensive subjects with an adjustable blood pressure cuff set at different widths: Fig. A—6 cm.; Fig. B—18 cm.; Fig. C—12 cm. (standard width), and Fig. D—width corresponding to 40 per cent of the circumference of the subjects arm ("adj.").

Upper half of figures—systolic pressures, lower half—diastolic pressures; one measurement per subject with each cuff width. Lines drawn according to regression formulæ calculated from the data. Correlation coefficients (r) and the probabilities of the coefficients (Pr) are given.

However, with the "adjusted" cuff, the correlation between pressures and circumference for both systolic and diastolic readings was reduced below the level of statistical significance. Also, the difference between the correlation coefficients of this relationship for the "adjusted" and the standard cuffs was significant at the 96 per cent level by the method of transformation (Fisher 1944, Arkin and Colton, 1957). Furthermore, inspection of the regression lines for the data (Fig. 6) showed that the use of the "adjusted" cuff gave the least rise in systolic or diastolic pressure with increase in arm circumference. Thus the error in reading due to deviation in the individual's arm circumference from that of the medium arm for which the standard 12 cm. cuff was devised, was corrected by introducing a corresponding variation in cuff width by use of the adjustable cuff.

The degree to which variation in the circumference of the arm contributes to the total variation due to all factors influencing blood pressure was determined ($100 \times r^2$, Table I). For systolic pressure, measured with the standard cuff, the arm circumference was found to account for 30 per cent of the variation, and for the diastolic pressure for 16 per cent. On the other hand, when the pressure was determined using the "adjusted" cuff, the comparable values were only 4 per cent and 2 per cent, respectively.

The extent of correction obtained with the "adjusted" cuff, expressed as the difference between the readings with the standard and "adjusted" cuffs, ranged up to 20 mm. Hg for both thick and thin arms. The extent of this difference is similar to that found by von Bonsdorff (1932) between indirect determinations with the standard cuff and direct intra-arterial determination.

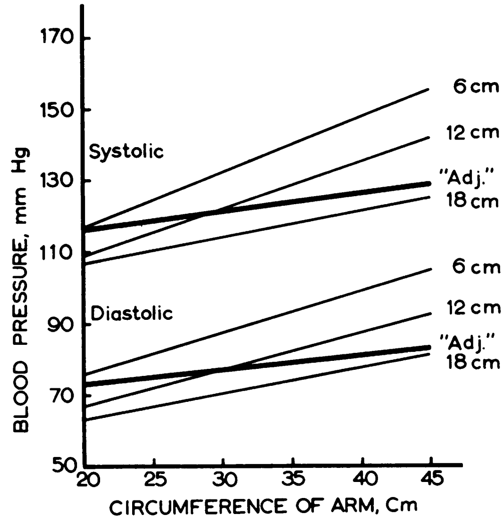

FIG. 6.—Comparision of regression lines for systolic and diastolic pressures for cuffs of different widths. Note minimal slopes of regression lines for "adjusted" cuff for both systolic and diastolic pressures.

DISCUSSION

The standard width of blood pressure cuff was set in 1901 when von Recklinghausen increased the width of Riva-Rocci's cuff from 5 to 12–14 cm. However, even with this larger standard cuff, deviations were frequently found from direct intra-arterial measurements (Pickering, 1955; Trout *et al.*, 1956).

Ragan and Bordley (1941) demonstrated a positive correlation between this discrepancy and the circumference of the subject's arm. Using their data, Pickering (1954) developed a table of corrections to adjust the indirect readings for this error. The corrections for systolic pressure ranged from +15 mm. Hg for arms 15–18 cm. in circumference to −25 mm. Hg for arms 46–49 cm. in circumference. For diastolic pressure the corrections ranged from 0 for arms 15–20 cm. to −25 mm. Hg for arms 44–47 cm. in circumference. However, as Pickering himself noted, these corrections are valid only when applied to the average blood pressures calculated for large groups of individuals and not for correcting the pressures of single individuals. This follows from the wide scatter of the individual readings above and below the average blood pressure for the group. Indeed, the application of Pickering's correction to the individual case may even increase the difference between the indirect reading and the true value. This is the disadvantage of the cuff proposed by Higham (1959) to facilitate the application of Pickering's correction to measurements of the blood pressure of individuals (see also Whyte, 1959).

Pædiatricians have been aware of the large errors that result when the standard cuff is used for small children or when narrow cuffs designed for infants are used for larger children (Robinow *et al.*, 1939). The effect of using a series of cuffs of different widths for adults was shown by Irving in unpublished work quoted by Smirk (1957).

In our study we have demonstrated the effectiveness of a single cuff adjustable in width to 40 per cent of the arm circumference in eliminating almost completely the error due to variations in the circumference of the arm. With this cuff the overestimation of blood pressure in individuals with large arms and its underestimation in those with small arms, resulting from the use of the standard cuff, was corrected.

Our use of the cuff adjusted to 40 per cent of the circumference of the arm was based on the recommendation of Bordley (1951) adopted by the American Heart Association, that cuff width should be about 120 per cent of the diameter of the arm. That recommendation appears to be simply an expression of the fact that the standard 12 cm. cuff gives values similar to those obtained by direct measurement in most adult subjects, in whom the usual arm circumference is about 30 cm. (diameter 9·5 cm.).

The regression lines obtained with the standard cuff and the "adjusted" cuff intersected at a point corresponding to an arm circumference of about 30 cm. (28·9 cm. for systolic and 30·6 cm. for diastolic pressures, respectively) (Fig. 6). The intersection of the regression lines at these points suggests the absence of significant systematic errors in much of our experimental procedure, and that folding the cuff is a valid expedient, for it follows that the regression lines for the adjusted cuff must of necessity intersect those of the standard cuff when the adjusted cuff is folded to the same width as the standard cuff. The difference between the arm circumferences at which the regression lines for systolic pressures for the standard and "adjusted" cuffs intersect and the difference between the slopes of the regression lines for systolic and diastolic pressures with the adjustable cuff are in keeping with the suggestion that the optimal cuff width ratio for diastolic pressure may be slightly different from that for systolic pressure. This suggestion was made by Robinow *et al.* (1939) on the basis of their work in infants and children using a series of 5 different cuffs varying in widths from 2·5 to 11·0 cm.

Studies to clarify this point in adults are planned, in which the adjustable cuff folded to widths corresponding to different proportions of the arm circumference will be used in conjunction with direct intra-arterial pressure determinations. These studies are also needed to provide direct confirmation of the effectiveness of the adjustable cuff in correcting blood pressure determinations.

It is possible that the low blood pressures reported for certain populations among whom the asthenic habitus is common (Alkaly, 1954; Whyte, 1958) to a large extent may represent an artefact related to the use of the standard cuff. This error could be eliminated by using the adjustable cuff, and comparisons of blood pressures between different populations could be put on a more reliable basis.

However, the most practical application of the adjustable cuff is in the proper selection of candidates for drug treatment of hypertension. Reducing blood pressure readings of obese individuals by 20 mm. Hg or more by eliminating the error caused by too narrow a cuff, will spare an undetermined number of patients unnecessary treatment of non-existent or negligible hypertension. Even obese patients with true hypertension will be spared overtreatment to reduce pressure levels that are already close to or even within normal limits, but that read high due to use of the standard cuff.

On the other hand, the temptation to treat the "primary hypotension" of certain asthenic individuals will be reduced since with the adjustable cuff the readings will come close to or within the usual blood pressure range.

SUMMARY

A blood pressure cuff designed to eliminate errors in measurement due to the use of the standard pressure cuff for arms of different sizes is described. With this cuff adjusted in width to 40 per cent

of the circumference of the arm, the positive correlation between circumference of arm and both systolic and diastolic pressure in 48 normotensive adults was effectively eliminated.

The use of this cuff may reduce blood pressure readings of certain obese individuals by 20 mm. Hg or more, and thus prevent unnecessary treatment of supposed hypertension. Low readings in asthenic individuals may also be corrected and brought closer to or within the normal range.

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